MASTER OF SCIENCE
IN
ASTRONAUTICAL ENGINEERING

A LASER METROLOGY SYSTEM FOR PRECISION POINTING

Edward J. Hospodar, Jr.-Major, United States Air Force
B.S., United States Air Force Academy, 1993
Master of Science in Astronautical Engineering-December 2003
Advisor: Brij N. Agrawal, Department of Mechanical and Astronautical Engineering
Second Reader: Hong-Jen Chen, National Research Council Research Associate

Precision spacecraft payloads are driving the need for fine pointing control and vibration cancellation. One implementation that provides pointing and disturbance control is the Stewart-Gough platform equipped with active sensing and actuating elements. The Precision Pointing Hexapod (PPH) at the Naval Postgraduate School (NPS) is exactly such a platform, initially installed with voice coil actuators and accelerometers on each strut by CSA Engineering, Inc. High pointing accuracy, however, requires an additional external sensing system that feeds back the accurate location and orientation information of the moving platform for control.

The first implementation by NPS of such sensing system is the eddy current metrology system. Currently, that system only provides measurement of the two degrees of motion that define the pointing direction and has issues such as questionable absolute pointing accuracy and lower resolution. This thesis seeks to develop a new laser metrology system, utilizing diode lasers and position sensing detectors, to provide all six degrees of freedom information of the platform motion at higher precision and accuracy. The tasks of developing the laser metrology system, from theory to design, fabrication, implementation, and verification, are documented in this thesis. Recommendations for future work and lessons learned are also captured.

KEYWORDS: Precision Pointing Hexapod, Stewart-Gough Platform, Stewart-Platform, PSD, Laser

FLEXIBLE MULTIBODY DYNAMICS AND CONTROL OF THE BIFOCAL RELAY MIRROR

Brian M. Moore-Captain, United States Army
B.S., Purdue University, 1993
M.S.A., Central Michigan University, 2001
Astronautical Engineer-December 2003
Master of Science in Astronautical Engineering-December 2003
Advisor: Brij N. Agrawal, Department of Mechanical and Astronautical Engineering
Second Reader: Marcello Romano, National Research Council Research Associate

In recent years, spacecraft have become increasingly flexible. The design requirements for the Bifocal Relay Mirror spacecraft include controlling jitter at the nanoradian level. Typically, tight pointing requirements require high structural stiffness, at the cost of increasing the on-orbit mass. To accomplish this, while minimizing the mass of the spacecraft, the structure will have some inherent flexibility. These flexible modes will interact with the pointing control, hence affecting the payload performance. The compensator design conducted in this thesis achieves order of magnitude improvements in controlling the rate error, hence jitter. This thesis starts with a rigid body dynamic model, and develops a flexible body dynamic model. Once the model is developed, the structure-controls interaction is discussed. Finally, compensators are applied to the rigid body controller to mitigate the performance losses present in the flexible body system. Through classical second-order compensators, the angular rate error was decreased by a factor of ten. Nonminimum phase notch filters and phase lag filters were used. Ultimately, the phase lag filters provided the best performance.

KEYWORDS: Controls, Flexible, Flexibility, Structure, Compensator, Filter, Bifocal Relay Mirror, Modal, Modes, Laser, Satellite, Spacecraft, MATLAB, SIMULINK, Attitude

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DESIGN AND OPTIMIZATION OF HYPERSONIC TEST FACILITY FOR SUBSCALE TESTING

Stephen R. O'Kresik-Lieutenant, United States Navy
B.S., University of Arizona, 1996
Master of Science in Astronautical Engineering-December 2003
Advisor: Jose O. Sinibaldi, Department of Mechanical and Astronautical Engineering
Second Reader: Garth V. Hobson, Department of Mechanical and Astronautical Engineering

In this thesis, the Rocket Propulsion and Combustion Lab at the Naval Postgraduate School is evaluated to determine if the installed gas support systems are capable of supplying the operation of a hypersonic test stand. Trait analysis is performed on the installed systems and the results are compared to the in flight conditions that would be required by a hypersonic combustor. Additionally, a simple method is developed to allow other institutions to easily evaluate their facilities. A software model including Matlab and Simulink models is also included to create a seamless analysis and change prediction tool.

KEYWORDS: Hypersonic Test Facilites, Hypersonic Testing, Vitiated Air, Vitiator

TRANSMISSION OF A DETONATION WAVE ACROSS A SUDDEN EXPANSION WITH VARYING MIXTURE COMPOSITION

Elizabeth J. Touse-Lieutenant, United States Navy
B.S., United States Naval Academy, 1997
Master of Science in Astronautical Engineering-December 2003
Advisor: Christopher M. Brophy, Department of Mechanical and Astronautical Engineering
Second Reader: Jose O. Sinibaldi, Department of Mechanical and Astronautical Engineering

Detonation waves were examined in axisymmetric and two-dimensional test configurations to determine the limits at which a detonation will successfully initiate and diffract from a small initiator tube into a larger main combustor. Tests were conducted for various initiator-to-main combustor area ratios. Additionally, for each area ratio, the fuel-oxygen initiator mixture was diluted with various nitrogen concentrations attempting to approach the mass fraction of nitrogen in air (79%).

Results of the axisymmetric testing showed that with an expansion area ratio of 2.0, detonations began to fail to initiate in the initiator section with nitrogen dilution as low as 45%. Although, through constructive interference such as wall reflections and shock-shock interactions, a detonation wave initiated in the main combustor for up to 60% nitrogen dilution. Results of the two-dimensional testing showed that for area ratios of 1.33 to 2.67, detonation waves successfully transmitted for all nitrogen dilution cases, including 79%. For an area ratio of 4.0, detonation waves successfully transmitted with 65% nitrogen dilution, but failed with 70% nitrogen dilution.

KEYWORDS: Pulse Detonation Engines, PDE, Detonation Diffraction

ANGULAR RATE ESTIMATION BY MULTIPLICATIVE KALMAN FILTERING TECHNIQUES

Vincent C. Watson-Lieutenant, United States Navy
B.S., Georgia Institute of Technology, 1994
Master of Science in Astronautical Engineering-December 2003
Advisor: Roberto Cristi, Department of Electrical and Computer Engineering
Second Reader: Brij N. Agrawal, Department of Mechanical and Astronautical Engineering

Spacecraft attitude estimation and pointing accuracy have always been limited by imperfect sensors. The rate gyroscope is one of the most critical instruments used in spacecraft attitude estimation, and unfortunately, historical trends show this instrument degrades significantly with time. Degraded rate gyroscopes have impacted the missions for several NASA and ESA spacecraft, including the Hubble Telescope. A possible solution to this problem is using a mathematically modeled dynamic gyroscope in lieu of a real one. In this thesis, data from such a gyro is presented and integrated into a spacecraft attitude estimation algorithm.

The impediment to spacecraft attitude estimation presented by imperfect sensors has been overcome by developing more accurate sensors and using Kalman filters to reduce the effect of noisy measurements. Kalman filters for spacecraft attitude estimation have historically been based on an Euler angle or quaternion formulation. Though Euler angles and quaternions are arguably the easiest methods with which to describe the attitude of a spacecraft, other methods of describing attitudes do exist – including the Gibbs and Rodriguez parameters. A Kalman filter based upon the Gibbs parameter is presented and analyzed in this thesis.

KEYWORDS: Kalman Filter, Gibbs Parameter, Dynamic Gyroscope, Attitude Estimation